600/3-80-075

United States
Environmental Protection
Agency

Environmental Research
Laboratory
Duluth MN 55804

EPA-600/3-80-075
July 1980

Research and Development

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A Remote Sensing Technique to Monitor *Cladophora* in the Great Lakes

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EPA-600/3-80-075
July 1980

A REMOTE SENSING TECHNIQUE TO MONITOR *CLADOPHORA* IN THE GREAT LAKES

by

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FOREWORD

Our nation's Great Lakes are vital for all animals and plants, yet our diverse uses of water--for recreation, food, energy, transportation, and industry--may physically and chemically alter these lakes. The presence of the nuisance alga Cladophora along parts of the Great Lakes' shoreline is one of the negative consequences of excess inputs of pollutants into the lakes and their contributing rivers and streams.

This report demonstrates the usefulness of airborne remote sensing to monitor the amount and distribution of shoreline algae problems.

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ABSTRACT

The feasibility of using an airborne multispectral scanner to monitor shoreline algae problems has been demonstrated. Multispectral data were collected at two sites on the U.S. Lake Ontario shoreline. Computer generated color maps were produced to show spatial distribution of *Cladophora* in the nearshore zone and to estimate standing crop.

Ground truth data as unit samples of bottom vegetation were collected at several locations which were marked in the imagery by surface floats.

A depth invariant model based upon principal component analysis was used to process seven passive bands between 0.46 and 0.70 μm. Spectral features of *Cladophora* were related to measured standing crop.

This report was submitted by the Environmental Research Institute of Michigan in fulfillment of Grant No. R803611011 under the sponsorship of the U.S. Environmental Protection Agency. All work was completed by October, 1977.

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ACKNOWLEDGMENTS

Several individuals contributed to the project. In particular, Mr. Robert A. Shuchman and Mr. Carl Davis of ERIM and Dr. Warren Flint and Mr. Joseph Hichar of the Great Lake Laboratory SUNY at Buffalo are acknowledged for their help with the field work. In addition, Mr. Kenneth Knorr is acknowledged with sincere thanks for his help with the multispectral processing. Thanks are also extended to Ms. Nancy Moon and Ms. Evelyn Wrabel for secretarial support.

SECTION 1

CONCLUSIONS

Results from the airborne multispectral data collection and analysis program on the Lake Ontario shoreline near Rochester, New York has led to the following conclusions:

(1) The airborne method of collecting information on the extent and growth of *Cladophora* in the nearshore zone has been demonstrated as a practical method of data acquisition over extended stretches of shoreline.

(2) Recognition of *Cladophora* biomass from aircraft imagery requires gathering *Cladophora* samples at known locations. Sampling locations can be marked with highly reflective floats which are visible in the multispectral imagery.

(3) The use of multispectral digital instrumentation allows development of automatic recognition techniques. Results can be displayed as high resolution maps for selected areas and to compile standing crop estimates over large reaches of shoreline.

(4) Since both areal distribution and standing crop measurements are possible, a method now exists for monitoring *Cladophora* growth on a multiyear basis.

SECTION 2

RECOMMENDATIONS

The airborne multispectral data collection and analysis program on the Lake Ontario shoreline has led to the following recommendations and suggested applications:

(1) Aircraft remote sensing should become a standard accepted technique to monitor or to map the distribution and biomass of benthic algal communities for the Great Lakes.

(2) Based upon these results and previous work completed in 1974, a complete *Cladophora* survey and monitoring program can be initiated for the Great Lakes (or portions thereof) leading to the establishment of a systematic historical data base.

(3) Specific influences of local sources of nutrient or various environmental contaminants on the growth and extent of *Cladophora* should be monitored using this aerial technique with multiyear surveys. Improvements in local water quality as a result of implementation of remedial programs can be expected to affect *Cladophora* growth and therefore are observable in the airborne surveys.

SECTION 3

INTRODUCTION

The filamenteous alga *Cladophora Glomerata* grows abundantly along a number of Great Lake shorelines. This benthic form grows selectively on hard surfaces and rocky substrates and appears to be the dominant species. *Cladophora* has long been an annoying problem for shoreline property owners, boaters, and users of public beach facilities. After an early and rapid period of growth, filaments are easily broken during summer storms. For the shoreline property owner subsequent decomposition of large masses of *Cladophora* produces obnoxious conditions. In addition, accumulated algae can force the closing of public recreational facilities.

Influx of nutrients from shoreline activities plays an essential role in the nutrition of the benthic algae. The location of *Cladophora* beds is frequently a good biological indicator of a nutrient pollution source. Changes in existing beds may indicate corresponding changes in the local cultural nutrient sources.

Little is known about the distribution and biomass of benthic algae in the Great Lakes. The International Joint Commission (IJC) committee for surveillance has recommended that a *Cladophora* monitoring program be developed. Aircraft remote sensing technology provides an ideal method for collecting the necessary information to assemble a Great Lakes *Cladophora* data base.

The Environmental Research Institute of Michigan (ERIM) has been involved in a *Cladophora* sensing program since the beginning of the IFYGL program in 1972. Under a research grant for the U.S. EPA (Grant No. 800778) ERIM studies reported by Wezernak, Lyzenga, and Polcyn [1] in 1974 have shown how airborne data can be used to estimate mass and extent of bottom growths.

The present study has been directed to further refine and develop multispectral scanner techniques which allow automatic recognition of distribution and biomass parameters when compiled with ground truth information. While color aerial photography can be used to identify fields of benthic algae, it cannot be easily processed quantitatively. The inherent problem in photographic analysis is correcting for changes due to water depth; which often coincide with changes in algal density. Development on the other hand, of depth-invariant digital techniques, for multispectral scanner data, can conveniently map benthic algae areal extent and biomass.

SECTION 4

METHODS

Data were collected using the Environmental Research Institute of Michigan (ERIM) remote sensing aircraft (C47). Multispectral data collection was initiated along the U.S. shoreline on June 15, 1977 from altitudes of 300 meters and 500 meters. Data were collected at two sites, Hamlin Beach (Site A) and Hilton Beach (Site B), New York, both of which were previously examined in the 1972 flights (Figure 1).

MULTISPECTRAL SENSOR SYSTEM

The ERIM M-8 active/passive multispectral scanner was used for remote sensing data collection [2]. Use of this instrument permits simultaneous data collection in nine passive spectral bands over a wavelength range from 0.44 to 1.5 μm. Additional detector positions are available for spectral bands in the ultraviolet and the infrared. The active data were collected using a nitrogen-dye pulsed laser system operating at 0.52 μm.

What is recorded is time history of the returned laser pulse, including surface reflection, scattering from water column, and bottom reflection. These components are separated in the time history, permitting independent analysis.

Pulsed laser data were collected on the June 15, 1977 flight at 300 meters altitude. These data could be potentially used in a *Cladophora* monitoring program to obtain a series of water depths (through extraction of the time difference between surface and bottom returns) for a single bottom type. Such information is useful to establish depth invariant signals where water depth data cannot be collected by survey crews. For the present program these laser data have not been processed.

Signals from passive detectors (as well as laser return pulse time history) are recorded on high density digital tape (HDDT) from subsequent image reconstruction and data processing are performed. Data from reference lamps and the solar irradiance sensors are also recorded. The scanner is positioned in the aircraft so as to provide continuous scanning perpendicular to the flight line as shown in Figure 2. As the aircraft advances, the rotating mirror scans the scene over a 90° field of view continuously so as to assemble an image line by line.

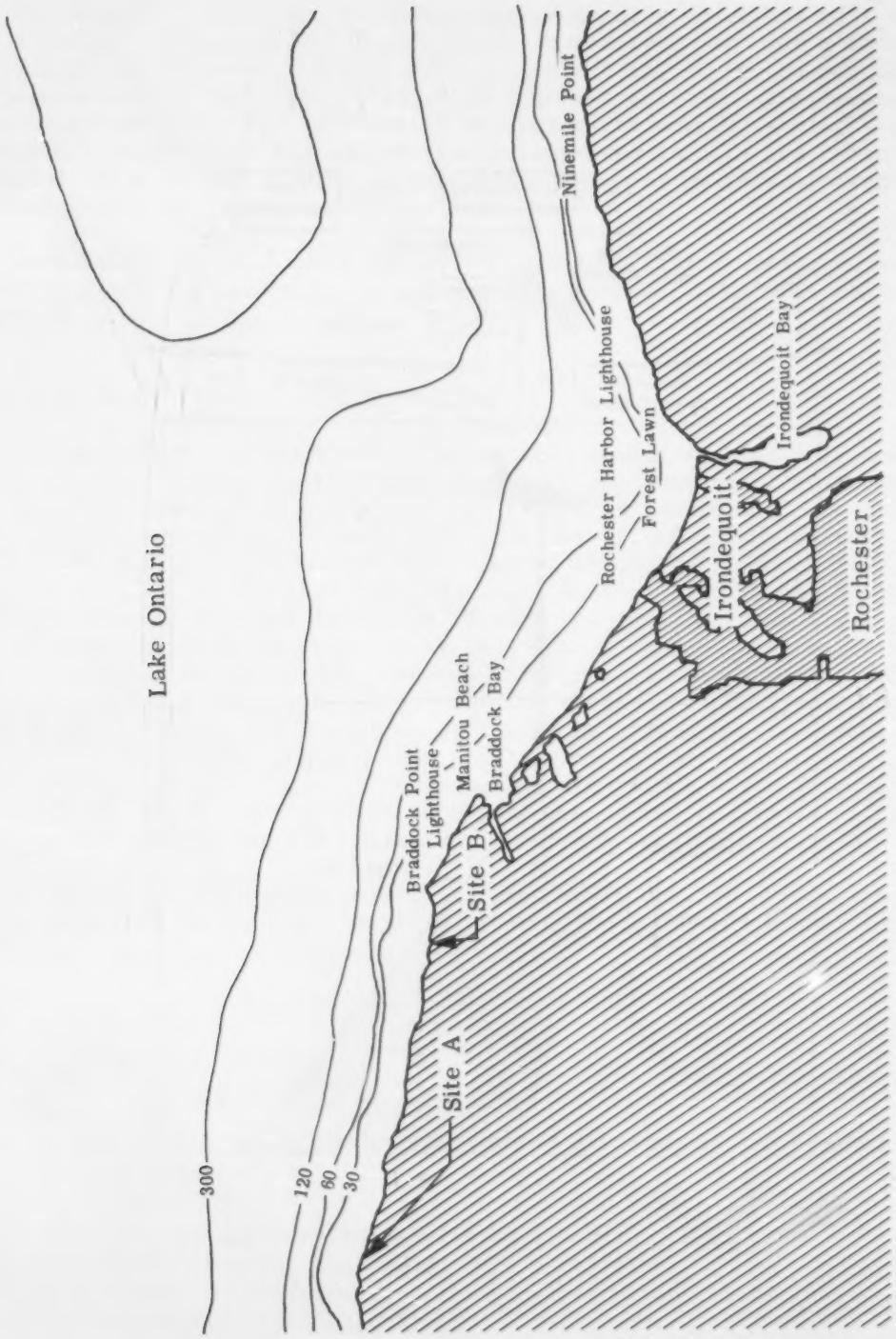

Figure 1. Location of Lake Ontario *Cladophora* monitoring sites.

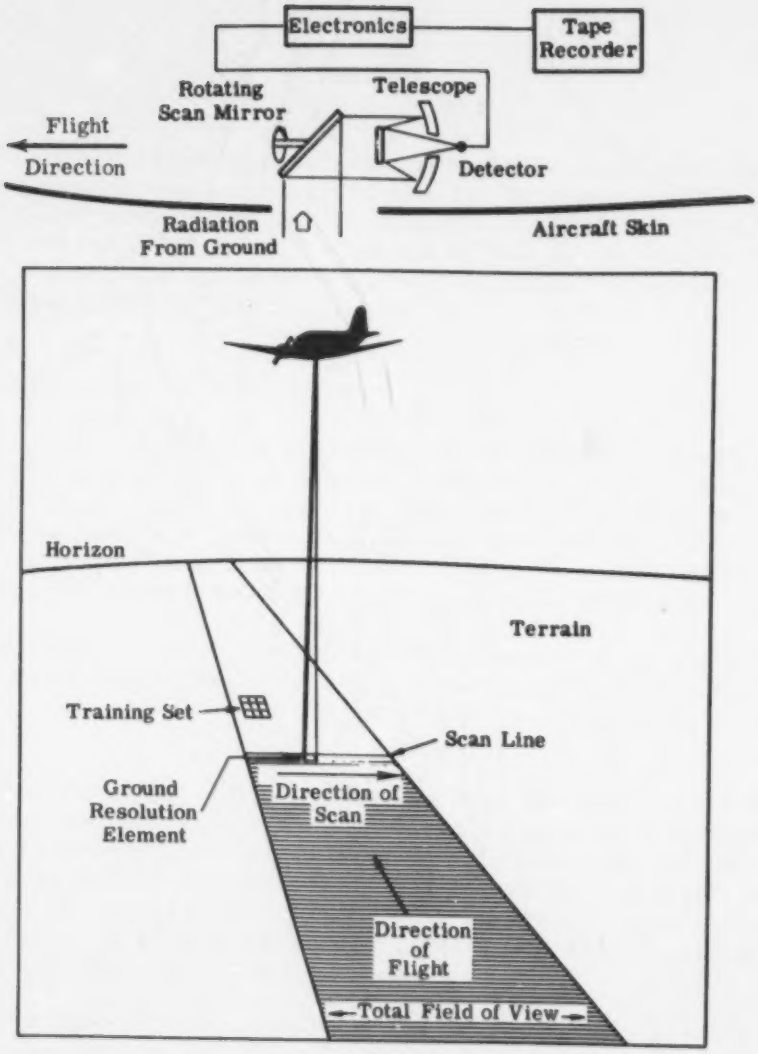

Figure 2. Geometry of airborne scanning.

The scanner imagery is stabilized electronically about the roll axis of the aircraft. No correction is made for aircraft pitch and yaw motion although the average yaw angle of the aircraft is recorded and the gross yaw correction can be made during data processing. The aircraft is flown at a constant preselected ground speed and altitude to establish the imagery scale factor. The geometrical accuracy of the imagery can be improved in data processing by trial and error in the current experimental system or by more accurate sensing of aircraft motion for an operational system.

In addition to data collected by the multispectral scanner, 70 mm black and white panchromatic and color photographic records were collected along the flight line.

Cladophora RECOGNITION BY REMOTE SENSING

The radiant energy received by an optical remote sensing instrumental system oriented toward a water body consists of components of scattered radiation from the intervening atmosphere and reflected radiation from the scene. At depths (and wavelengths) where radiation penetrates to the bottom, the latter component includes bottom reflectance, volume reflectance from the water column, and reflectance from the water surface. In the ERIM multispectral scanner, incident radiation is measured by a sun sensor and reflected or emanating radiation is measured by the scanner system. Utilization of this information to describe bottom features which result in radiation changes requires a model or models which account for the important interactions and their effects. Since the radiation reflected by bottom features must pass through the intervening water column, the amount of radiation reaching the sensor at a given wavelength is dependent on the volume attenuation characteristics of the water. Attenuation is a function of the thickness of the water layer and the absorption and scattering properties of the water.

In practice, the sensor output is recorded as voltage (V) on magnetic tape. Neglecting atmospheric effects, the bottom-reflected signal in a given spectral channel may be written as:

$$V_\lambda = VS_\lambda + k_\lambda \rho_\lambda e^{-(\sec \theta + \sec \phi) a_\lambda z} \qquad (1)$$

where V_λ = voltage received

VS_λ = surface reflectance

k_λ = constant which incorporates solar irradiances and scanner characteristics

ρ_λ = bottom reflectance

θ = viewing angle (from vertical)

ϕ = solar illumination angle (from vertical)

a_λ = volume attenuation coefficient (absorption coefficient + scattering coefficient)

z = water depth

λ = spectral wavelength.

Since water depth is variable, the signal received from an identical bottom feature will vary with depth. From an operational standpoint, a depth-invariant model is required which in effect permits removal of the signal because of overlying waters and water surface effects. One approach to the problem is the use of a ratio of two spectral bands with similar water attenuation coefficients. Writing the above expression in terms of two spectral bands results in:

$$\frac{V_1 - VS_1}{V_2 - VS_2} = k_3 \left(\frac{\rho_1}{\rho_2}\right) e^{-(\sec \theta + \sec \phi)(a_1 - a_2)z} \tag{2}$$

where $\frac{k_1}{k_2} = k_3$.

In cases where a_1 is equal to a_2,

$$\frac{V_1 - VS_1}{V_2 - VS_2} = k_3\left(\frac{\rho_1}{\rho_2}\right). \tag{3}$$

For a single bottom type, the ratio signal received from two channels (when $a_1 = a_2$) is directly proportional to bottom reflectances and, therefore, depth invariant. Use of the above expression for differentiating between *Cladophora* and background bottom types requires significant differences in bottom reflectance for the selected spectral pair.

While the ratio algorithm provides a suitable means to classify the bottom type, it does not take full advantage of all the spectral data collected by the aircraft scanner. The ratio takes two properly selected channels and produces a single depth invariant channel.

The generalized approach utilizes n separate data channels and produces n-1 possible depth invariant channels. The use of a multispectral technique can enhance the *Cladophora* areal mapping in two ways: the greater spectral detail should provide greater opportunity to distinguish the density and biomass of *Cladophora* beds, and the use of multiple channels tends to reduce errors of mapping caused by random noise.

The multispectral technique developed to process the present data collected is basically an extension of the ratio algorithm discussed above. As done in the previous work the spectral data must be after corrected for scan angle and surface reflectance effects. Each spectral channel can then be represented by the second term of equation (1). These representations for signals from a single bottom type or constant spectral reflectance are the components of a water depth vector for the multispectral signature. Signal variants which are orthogonal to the depth vector are depth invariant and describe other reflectance features by the signature [3]. The raw data can be visualized as a cloud of points with an elongation in the direction of the water depth dimension (Figure 3). Depth invariant components are obtained by projecting corrected data onto a plane which is oriented orthogonally to the estimated depth vector. The statistical method of principal components was

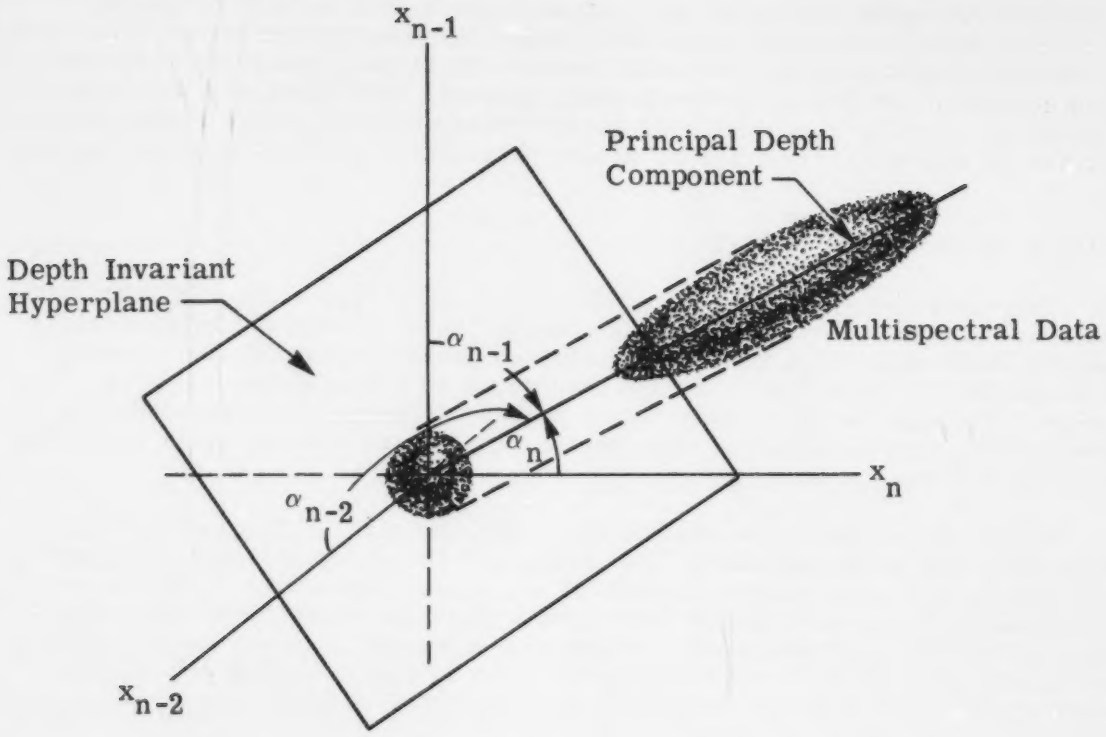

Figure 3. Development of depth invariant signatures.

used to derive the direction cosines for the depth vector from data with a uniform bottom type. In order to analyze the projected feature space for *Cladophora* spectral variants, data from the ground truth derived training sets are first converted to depth invariant images by projecting along the depth vector. The principal components of the transformed training set in turn yield orthogonal directions of maximum variation. The objective is to find the greatest spectral variants in the reflectance data and relate the values of that variant to the measured *Cladophora* standing crop.

A rationale for this approach is as follows. The standing crop per unit area will vary with the number of filaments per unit area and the nominal filament length. As these parameters change, so does the amount of chlorophyll a and transparent cell wall material which will in turn change the spectral characteristics of the bottom reflected radiance. The spectral measure of *Cladophora* standing crop developed for the present data, is the vector projection of the spectral signature on the principal *Cladophora* spectral variant.

WEATHER AND SEA STATE REQUIREMENTS

Three related environmental conditions - sea state, solar radiation conditions, and cloud cover - limit the observation of *Cladophora* by aircraft. Onshore waves will bring littoral bottom sediments into suspension causing increased water turbidity. In Lake Ontario, a 10 mph onshore wind will severely increase water turbidity in a matter of hours. Once suspended by wave action, particulates may take one or two days to settle, again producing acceptable water transparency.

During mid-summer, the southshore of Lake Ontario is frequently impacted with windy and stormy weather. The frequently turbulent sea state combined with debris from open lake productivity and broken *Cladophora* filaments produces nearly continuous turbid conditions. This was exactly the situation when a *Cladophora* reconnaissance flight was attempted in early August 1975. Conditions turned out to be sufficiently poor so that the collected multispectral data could not be processed for *Cladophora* distribution.

Besides sea state conditions, cloud and solar radiation conditions are important to obtain useful imagery. A thirty or forty percent cloud cover is considered the maximum tolerable. Overcast conditions reduce the incident sunlight so that insufficient contrast and the signal to noise ratio become problems. The June 1977 flight conditions were considered ideal. Two days of calm weather preceded the day of flyover. On that day the sea state was calm and skies were clear. Secchi transparency was 4.0 meters.

DATA PROCESSING

Multispectral scanner data collected over Lake Ontario were processed for *Cladophora* recognition with the previously described digital techniques. Aircraft high density tapes were first converted to computer compatible tapes (CCT's) during which corrections were made for scan angle and surface reflectance effects.

For each of the two shoreline sites, line prints were made for selected channels. Within each scene, pixels were determined which are co-located with ground truth sampling stations and fathometer transects.

For this experiment sampling station positions were made visible in the multispectral imagery through the use of station marker floats. Two types of training sets were abstracted from the data: signals from areas with uniform sandy bottom type with varying water depth and signals from areas immediately surrounding each ground truth station. The first set was used to establish multispectral variants for water depth while the second set was used to define the relationship between *Cladophora* standing crop and the multispectral signature. This latter relationship was obtained with computer algorithms which included deriving a depth invariant subset and performing principal component analysis. The resultant is a spectral vector which was used to describe the variation observed in *Cladophora* standing crop.

SECTION 5

GROUND TRUTH PROGRAM

Ground truth data consisting primarily of *Cladophora* bottom samples and water depth information were collected at two sites on Lake Ontario east of Rochester, New York. These two sites were included in the 1972 IFYGL Lake Ontario *Cladophora* flights (EPA Grant 660/3-74-028) [1]. The aircraft flights were made on June 15, 1977. Field sampling work was conducted from June 14 through June 16, 1977. Staff members from the Great Lakes Laboratory, SUNY at Buffalo assisted in the bottom survey.

FIELD METHODS

Samples were collected at specific stations at each site located in different bottom types and *Cladophora* densities. Stations were located by surface float or on transects through two or more such floats. The floats consisted of four inflatable panels in a cross pattern (see Figure 4). The cross pattern was distinctive and could be easily recognized in the resulting imagery. The panels were teathered with four suspended anchors, one on the end of each float and one central bottom anchor to fix the float position. This float design was inexpensive, easily assembled, expendable, and produced a high reflectance. Durability was not required since these floats were used only under good weather conditions required for the aircraft mission. Bottle buoys were used to mark locations at other times.

Five marker floats were employed at each site. A total of twenty one samples were collected between the two sites. At each station samples were gathered by cropping all plant material within a $0.17m^2$ wire hoop.

In addition to the bottom samples, water depth and other information were recorded. At many of the stations, underwater photographs were taken which provided valuable additional information on bottom conditions. Samples were returned to ERIM and subsequently analyzed for wet, dry, and free-ash weight according to Standard Methods [4].

FIELD DATA

Cladophora ground truth information is summarized in Tables 1 and 2. Besides these data light attenuation, transparency, and spectral reflectance measurements of bottom materials were made using an ISCO Model SR spectrometer. Percent reflectance values over the useful spectral wavelengths for the various

bottom types are shown in Figure 5. The fact that these values are quite different for each bottom type suggests that bottom classification can be accomplished with remote sensing techniques.

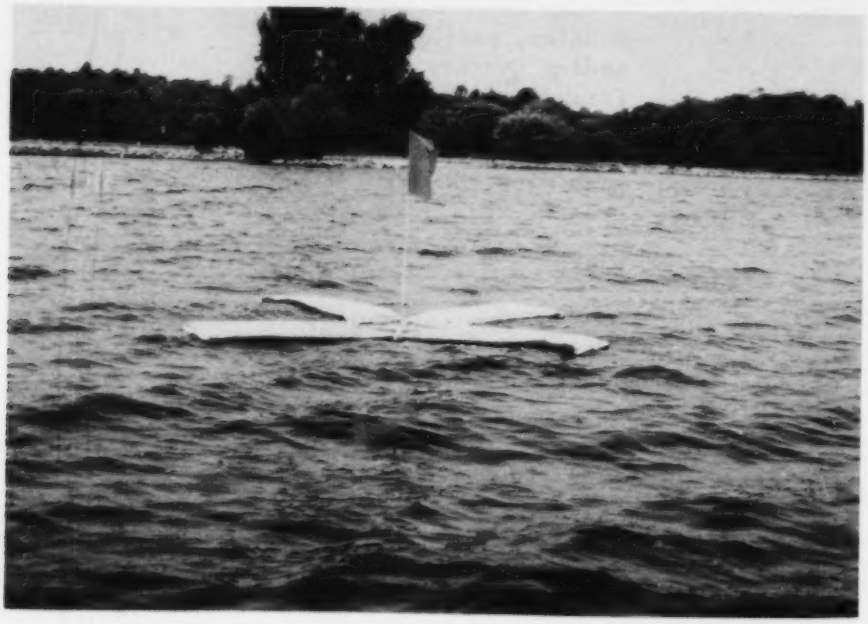

Figure 4. Surface float.

TABLE 1. *CLADOPHORA* GROUND TRUTH DATA
SITE A, HAMLIN BEACH STATE PARK, NEW YORK

Date: 15 June 1977

Float stations	Water depth (m)	Description	Wet weight (g/m^2)	Dry weight (g/m^2)
A1	3.3	Cobbles, patchy growth, medium density, 2-3" filaments, 40% cover	92	46.7
A2	2.6	Boulders interspaced with sand, healthy growth, medium density, 3-4" filaments, 45% cover	300	95.6
A3	1.8	Medium cobbles, medium density, bleached end filaments, 5-7" filaments 95% cover	460	134.0
A4	1.2	Small to medium cobbles, dense growth, bleached end filaments, 8-15" filaments, more than 95% cover	2100	503.0
A5	4.1	Small to medium cobbles, patchy-healthy growth, medium density, 1-2" filaments, 50% cover, high sediment content	140	82.1
Transect stations				
AT1	6.1	Sand		
AT2	4.6	1% cover	<10	0.7
AT4	2.9	40% cover	250	111.0
AT5	2.4	Poor conditions, 30% cover	32	14.3
AT6	1.8	Healthy, 90% cover	670	167.0
AT8	1.2	Healthy, more than 95% cover	940	212.0

TABLE 2. *CLADOPHORA* GROUND TRUTH DATA
SITE B, HILTON BEACH, HILTON, NEW YORK

Date: 16 June 1977

Float stations	Water depth (m)	Description	Wet weight (g/m^2)	Dry weight (g/m^2)
B1	3.2	Medium cobbles, stubby-patchy growths, 1-2" filaments, 15% cover	20	9.87
B2	2.7	Sandy patch surrounded by *Cladophora*, sparse to dense growth, 75% cover	High Sediment Content	71.10
B3	2.8	Large cobbles, dense growth, 4-12" filaments, 90% cover	520	117.00
B4	1.8	Large flat rocks and small cobbles, dense growth, 9-12" filaments, more than 95% cover	660	166.00
B5	1.7	Medium cobbles, dense growth, 4-8" filaments, more than 95% cover	830	153.0
Transect stations				
BT1	4.0	Healthy, 1" filaments, 40% cover	138	65.1
BT2	3.7	Pebbles and large boulders, 1-3" filaments, 60% cover	141	36.4
BT4	2.7	Sand in large patch		
BT5	2.1	More than 95% cover	580	83.9
BT7	2.1	30% cover	66	23.7

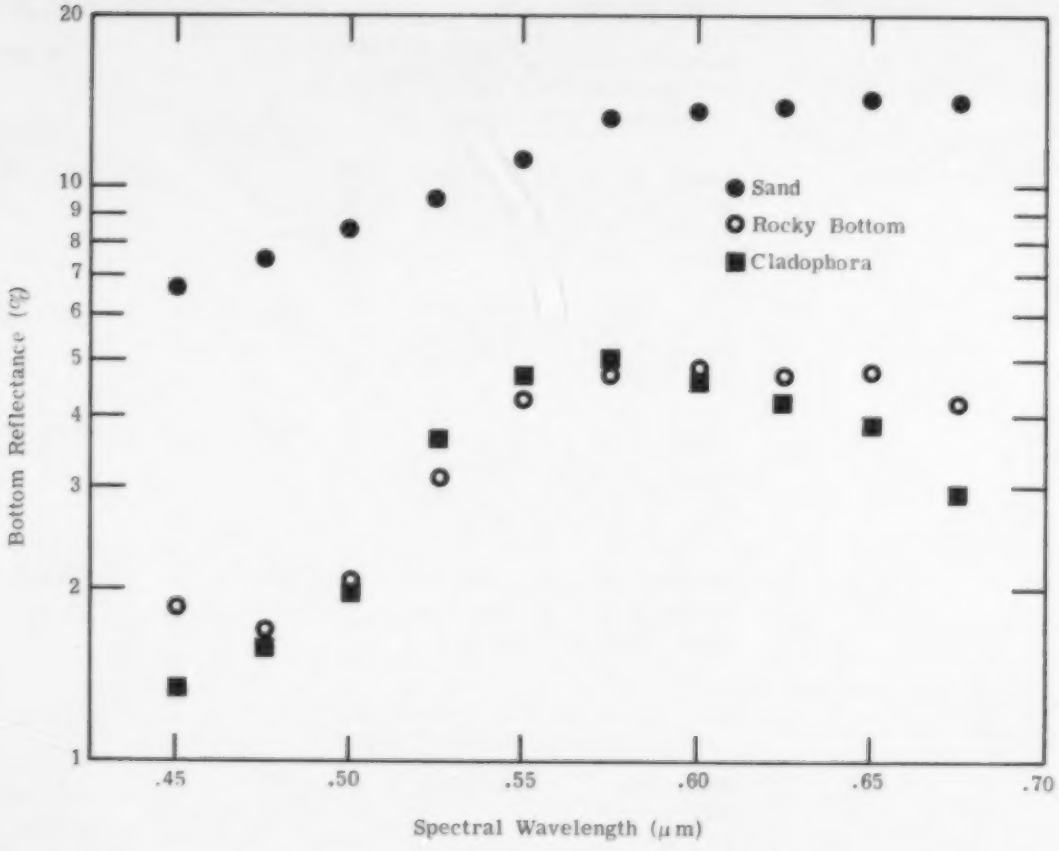

Figure 5. Spectral bottom reflectances measured at Hamlin Beach, New York on June 15, 1977.

SECTION 6

RESULTS AND DISCUSSION

Aircraft multispectral and ground sampling data were collected under excellent conditions which occurred on June 15, 1977. A total of six flight passes were made over the two sites during the times of minimum sun glint. Of all the data, only the morning flight data were free of any solar glint problem. The 500 meter altitude data were selected for processing at both sites because it produced a good swath width coverage of 1000 meters. A 2,100 scan line (2.1 km) section located in the vicinity of the *Cladophora* sampling data was assembled for analysis.

A total of 21 *Cladophora* samples were available to calibrate the two sites. A 200 point area (15 meters x 15 meters) surrounding each ground truth site was averaged over each of seven multispectral channels. The resulting *Cladophora* matrix was 21 by 7 values. Channels selected for analysis included:

Band 1: 0.46 - 0.49μm
Band 2: 0.48 - 0.52μm
Band 3: 0.50 - 0.54μm
Band 4: 0.52 - 0.57μm
Band 5: 0.55 - 0.60μm
Band 6: 0.58 - 0.64μm
Band 7: 0.62 - 0.70μm.

The sand bottom multispectral set (sand) which was generated from portions of five transect sets contained 48 values. Each value represents an average over 3 x 3 pixels. Depth range for the sand set was one to five meters, which covers the depth range at which *Cladophora* were found.

Principal component analysis (PCA) of the sand set produced essentially a single component of data in the direction of multispectral variation due to water depth. The eigenvector for the first component was (0.3787, 0.3786, 0.3690, 0.3840, 0.3729, 0.3790). The corresponding eigenvector accounted for 95.6% of the total variation in the sand data set.

Because of the exponential nature of light attenuation in water, the linear depth vector is only approximate. Absolute errors were estimated to be minimal at shallow depths and not to exceed 5% of any single multispectral channel at a depth of five meters. Since the major portion of *Cladophora* biomass is located at depths much less than five meters, errors resulting from the linear assumption are not considered to be great.

Using the above sand eigenvector a depth invariant subset of the *Cladophora* data set (CLAD), was derived with matrix rotation and projection methods. The derived set could then be examined using PCA for principal spectral features which were depth-invariant. Eigenvectors C_1 and C_2 are corresponding eigenvalues obtained from analysis of the depth invariant CLAD training set were:

C_1: (0.3431, 0.4027, 0.3829, -0.3951, -0.3924, -0.4025, -0.3172) and
C_2: (0.5737, -0.0768, -0.2962, -0.1186, -0.2990, -0.0048, -0.6882);

Percent of total variation explained by C_1 = 87.0%;
Percent of total variation explained by C_2 = 9.2%;
By all other components 3.8%.

Thus, the depth invariant *Cladophora* data (CLAD) can be practically represented by a single component C. Projecting all of the SAND/CLAD data onto the C_1/C_2 plane shows how the data can be spectrally separated (see Figure 6). Furthermore, the CLAD data which project furthest along the C_1 vector from C_2 had the greatest biomass. *Cladophora* samples which resulted in a projection close to C_2 had low biomass and sparse cover. The separation dimensionally between the sand and *Cladophora* data allows the use of a discriminant based upon $[C_1,C_2]$ which can separate these two basic bottom types. The C_1 vector alone becomes in this instance a good measure of the amount of *Cladophora* present.

The relationship between observed standing crop as grams dry weight per square meter and the derived multispectral measure, component vector C_1, is shown in Figure 7. While there is much scatter, especially for the low values of standing crop, a definite linear trend appears. The position of several of the data points as plotted in Figure 7 were found to be suspect after closer examination. These were: A5, B2 *Cladophora* samples have high sediment content; BT7 located on edge on rapdily changing bed of *Cladophora*; BT4, AT2, AT1 samples from sandy and rocky areas with very little *Cladophora* present.

A linear regression analysis was performed on the data shown in Figure 7 after deleting the above suspect data. This analysis produced a regression correlation coefficient of 0.94 and a linear relationship of: Standing crop = 1.81 + 1.46 (C_1, D) (g dry weight/m^2), where (C_1, D) is the vector projection of C_1 on the multispectral data vector D.

By projecting the entire data set along C_1 and classifying the sandy bottom areas, the original seven dimensional multispectral data set was reduced to a single variable which describes the amount of *Cladophora* present. Using this derived *Cladophora* measure of standing crop the multispectral data sets for each of the two sites were converted into single channel digital maps. Those maps were then in turn displayed on ERIM's MIDAS computer system by level slicing the signal into distinct ranges of standing crop. Figures 8 through 12 show the resulting maps and corresponding aerial photographs. Using site A as a validation test map and B as a calibration site, map values of predicted biomass compare quite well with that of field samples.

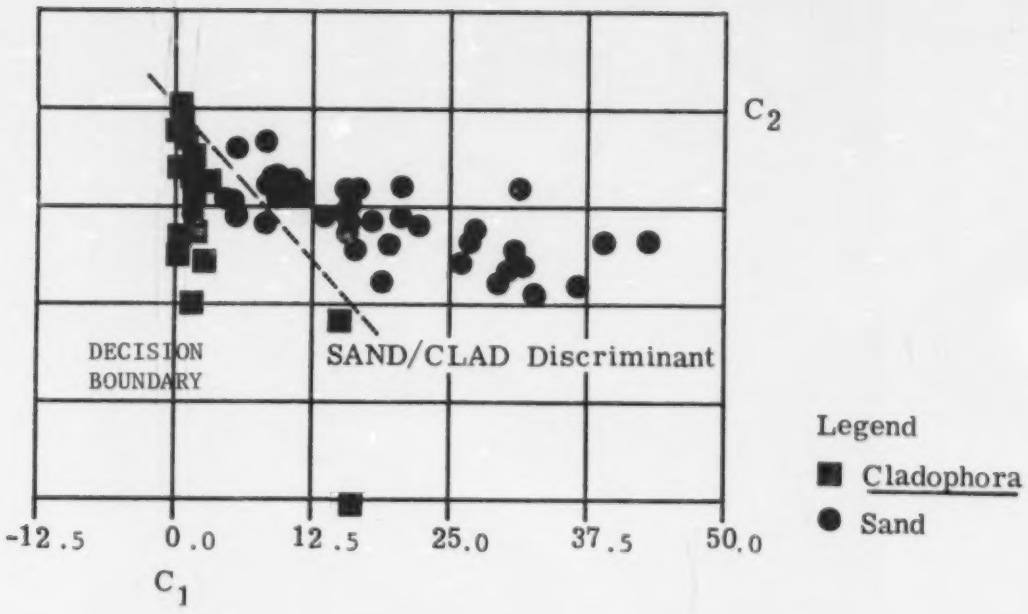

Figure 6. Projection of training sets on *Cladophora* Principal Components C_1 and C_2.

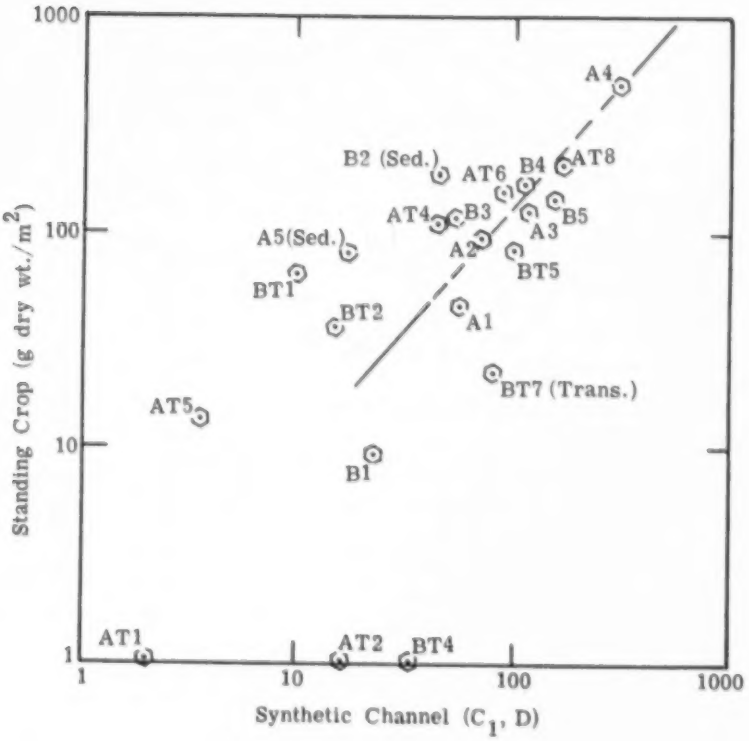

Figure 7. Relationship betweeen standing crop and the multispectral *Cladophora* measure.

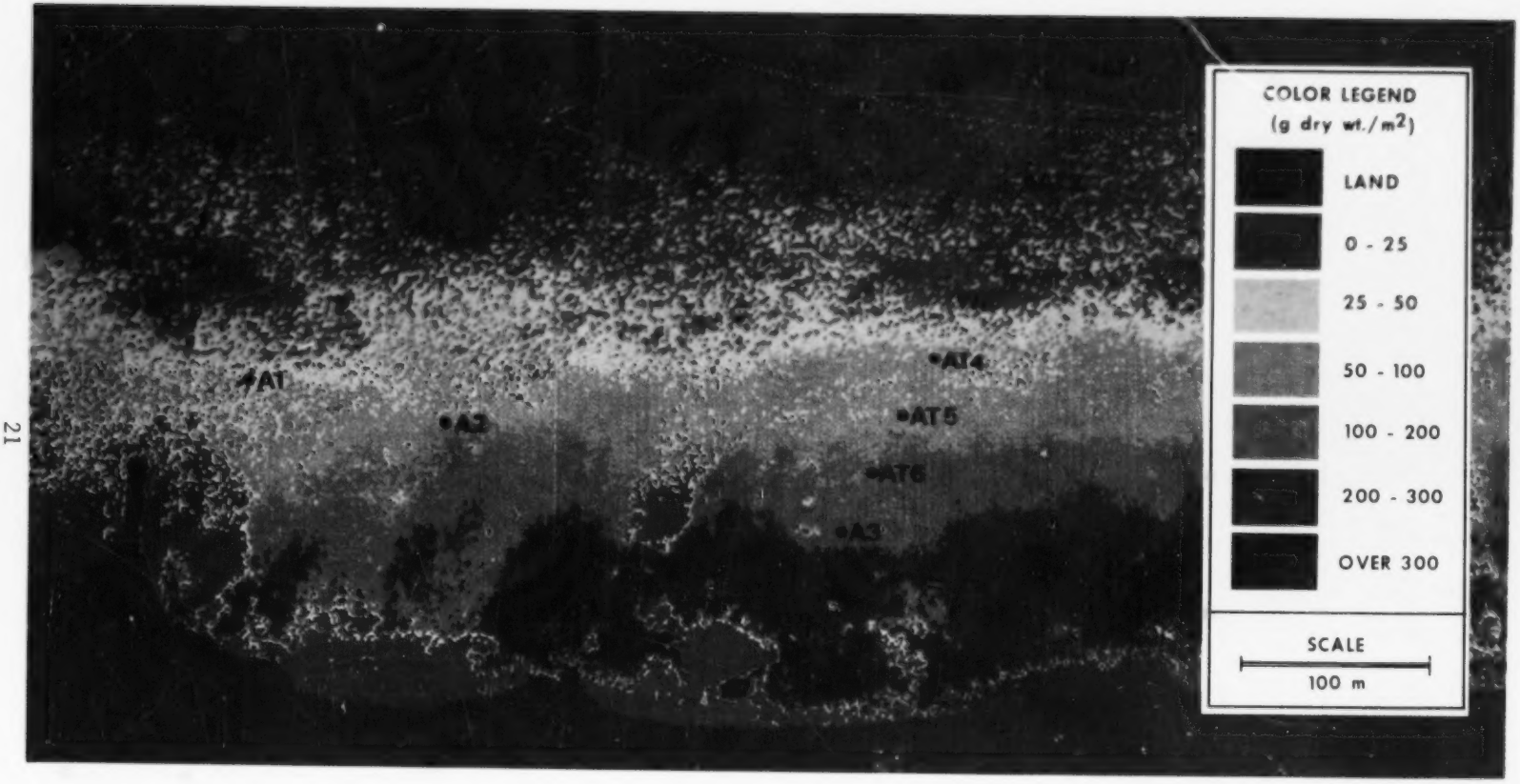

Figure 8. *Cladophora* recognition map, distribution and standing crop (g dry wt/m^2), site A, Hamlin Beach, New York.

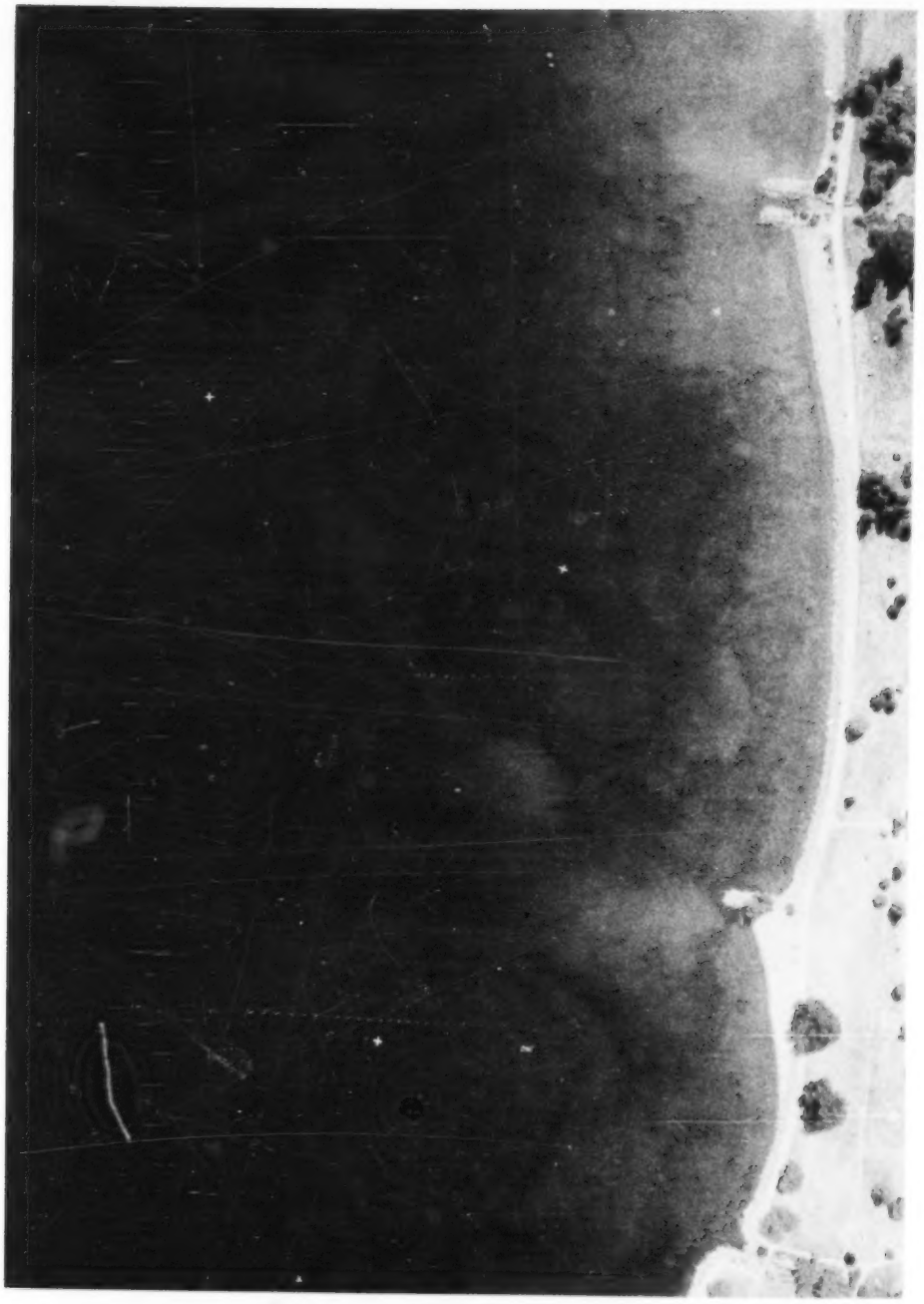

Figure 9. Aerial photograph, Site A, Hamlin Beach, New York.

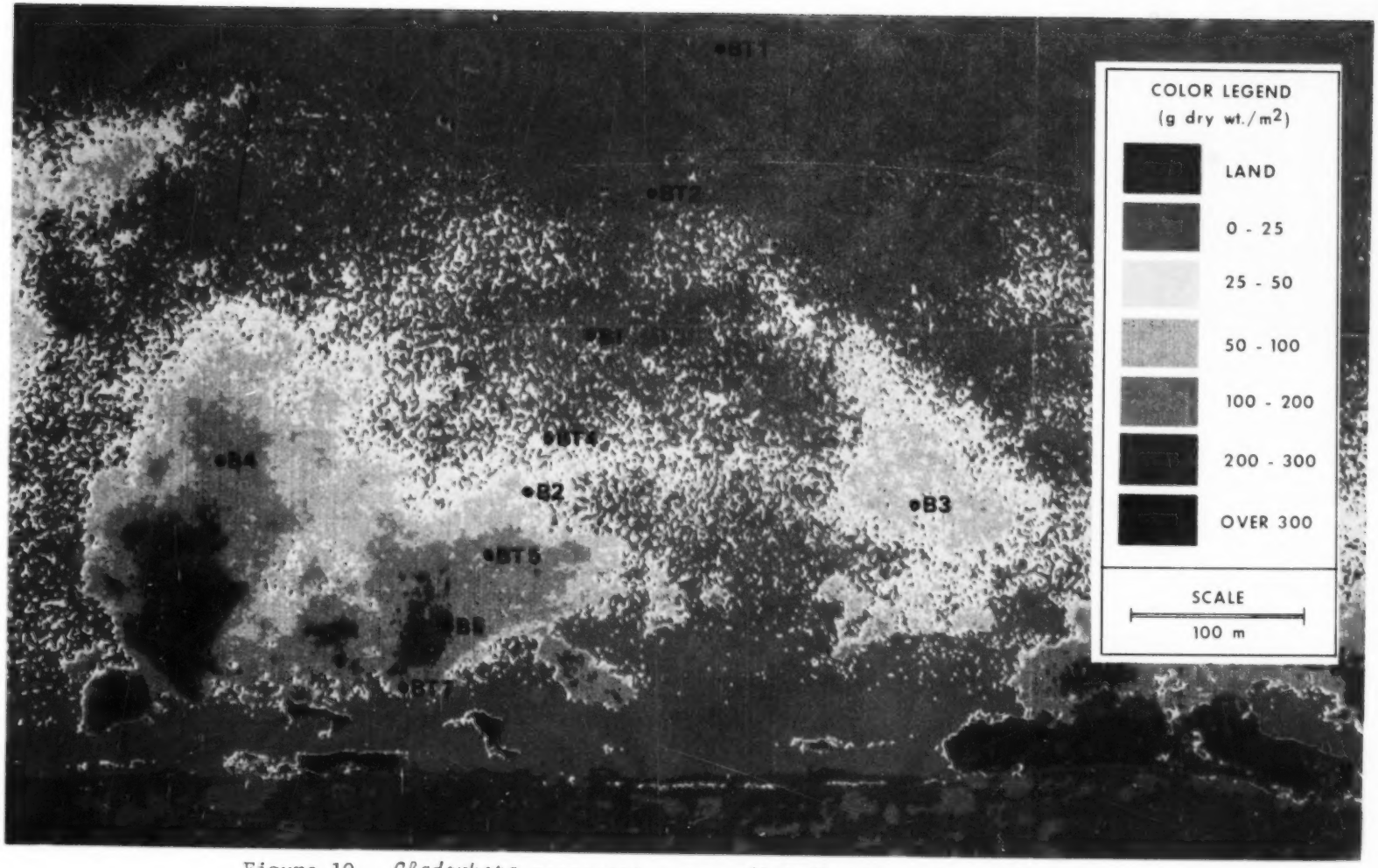

Figure 10. *Cladophora* recognition map, distribution and standing crop 9g dry wt/m^2), site B, Hilton Beach, New York.

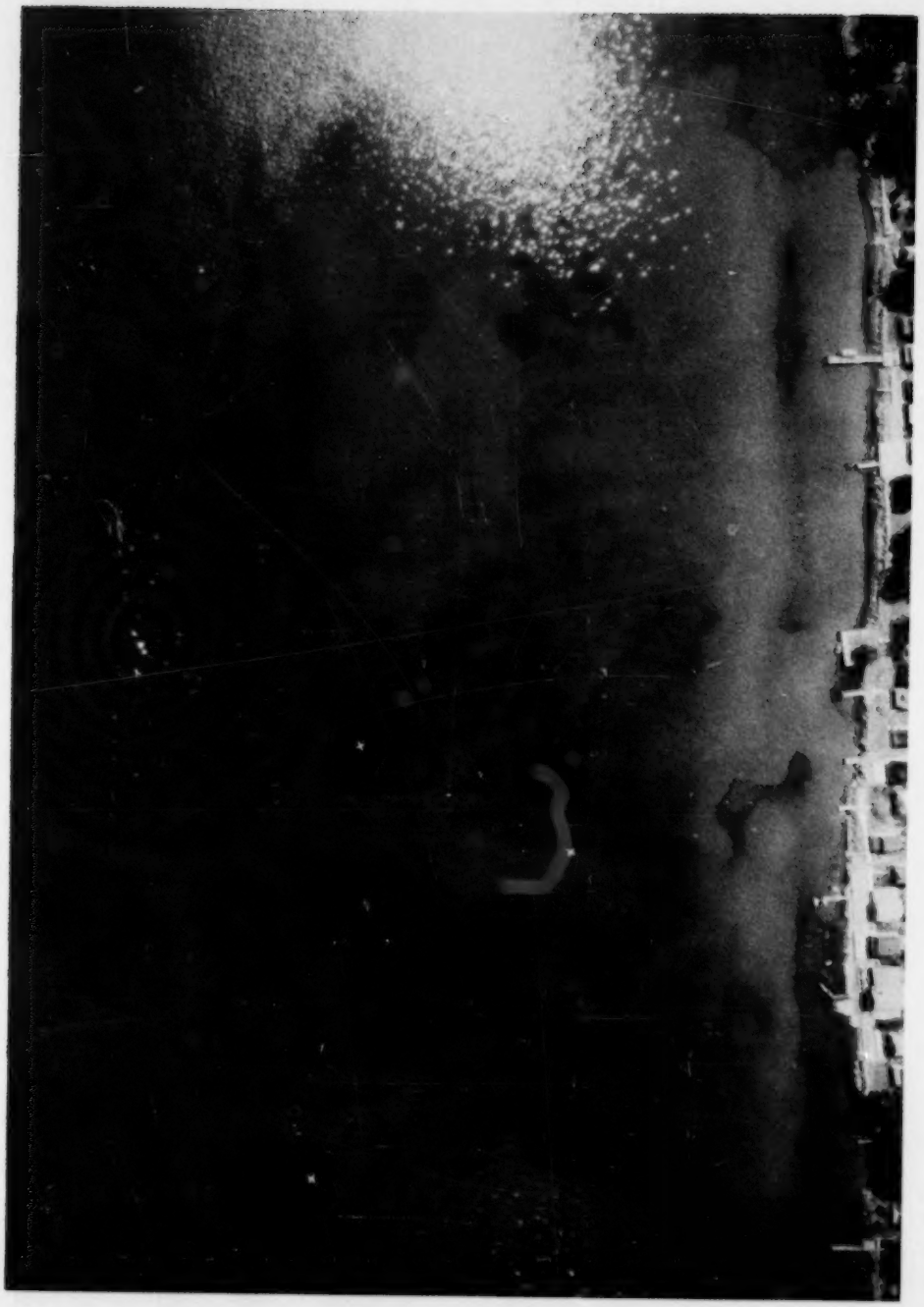

Figure 11. Aerial photograph, Site B, Hilton Beach, New York.

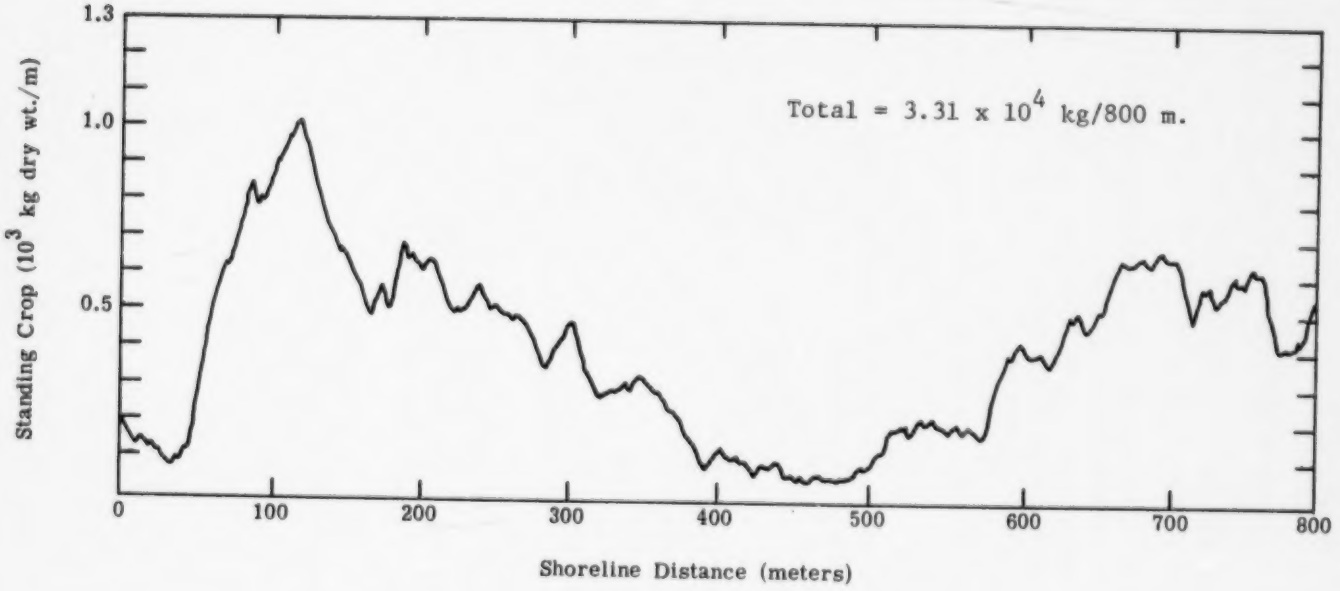

Figure 12. Shoreline profile, *Cladophora* standing crop (10^3 kg dry wt/m), Site B, Hilton Beach, New York.

Corresponding *Cladophora* maps produced from the 20 June 1972 data as ratio imagery can be found as Figure 9, page 23 and Figure 10, page 24 in the 1974 IFYGL *Cladophora* Report [1].

Comparison of the photographs with the computer maps indicates that very good recognition of *Cladophora* resulted from using this automatic technique. Obviously the accuracy of the maps decreases with decreasing standing crop. Values below 50 grams per square meter are not considered reliable.

All of the sand/*Cladophora* boundaries nearshore are well defined. In deep water the map shows mixed lower levels of standing crop as the *Cladophora* beds thin out with decreasing cover and filament length. At depths greater than five meters little *Cladophora* was observed on the rocky bottom probably because of the low light level condition.

It is not practical to image all *Cladophora* digital data that would be generated in any large survey using this technique. The detailed spatial distribution of *Cladophora* can be obtained readily from aerial color photography. The photography serves as a good permanent record of location and qualitative extent of the *Cladophora* beds except where depth obscures the standing crop. The quantification of the amount of *Cladophora* present is best obtained by processing the multispectral data. Standing crop estimates per unit of shoreline can then be calculated by summing over the *Cladophora* data fields. In the present work the estimated standing crop was summed over each scan line of the Hilton Beach data. The result is a *Cladophora* standing crop shoreline profile which shows the total standing crop per meter of shoreline (See Figure 12). The flexibility of the high resolution digitally processed data will allow estimation of standing crop over any desired spatial unit. While high resolution is needed to estimate standing crop results can obviously be displayed with much coarser resolution.

In large scale survey programs where results can be displayed as low resolution shoreline profiles incremental aircraft survey costs are expected to be in the range of $50 to $100 per linear mile. Additional cost would be expected for ground sampling and overall program planning and management.

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TECHNICAL REPORT DATA
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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/3-80-075		

4. TITLE AND SUBTITLE	5. REPORT DATE
A REMOTE SENSING TECHNIQUE TO MONITOR CLADOPHORA IN THE GREAT LAKES	July 1980 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Fred J. Tanis	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Environmental Research Institute of Michigan Infrared and Optics Laboratory Ann Arbor, Michigan 48107	1BA769
	11. CONTRACT/GRANT NO.
	Grant No. R803611
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Environmental Research Laboratory-Duluth Office of Research and Development U.S. Environmental Protection Agency Duluth, Minnesota 55804	Final 1975-1977
	14. SPONSORING AGENCY CODE
	EPA/600/03

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The feasibility of using an airborne multispectral scanner to monitor shoreline algae problems has been demonstrated. Multispectral data were collected at two sites on the U.S. Lake Ontario shoreline. Computer generated color maps were produced to show spatial distribution of Cladophora in the nearshore zone and to estimate standing crop.

Ground truth data as a unit samples of bottom vegetation were collected at several locations which were marked in the imagery by surface floats.

A depth invariant model based upon principal component analysis was used to process seven passive bands between 0.46 and 0.70 micrometers. Spectral features of Cladophora were related to measured standing crop.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Remote Sensing Monitors Detectors	Eutrophication Cladophora Lake Ontario Imagery	08/H

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	UNCLASSIFIED	36
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (9-73)

☆ USGPO 661-099 9/80

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